Very Forward Instrumentation of the ILC Detector

On behalf of the

FCAL Collaboration

High precision design

Wolfgang Lohmann,
DESY

FCAL Collaboration

High precision design

'Old' Kernel

Univ. of Colorado, Boulder,
AGH Univ., INP & Jagiell. Univ. Cracow,
JINR, Dubna,
NCPHEP, Minsk,
FZU, Prague,
IHEP, Protvino,
TAU, Tel Aviv,
DESY, Zeuthen

New Members

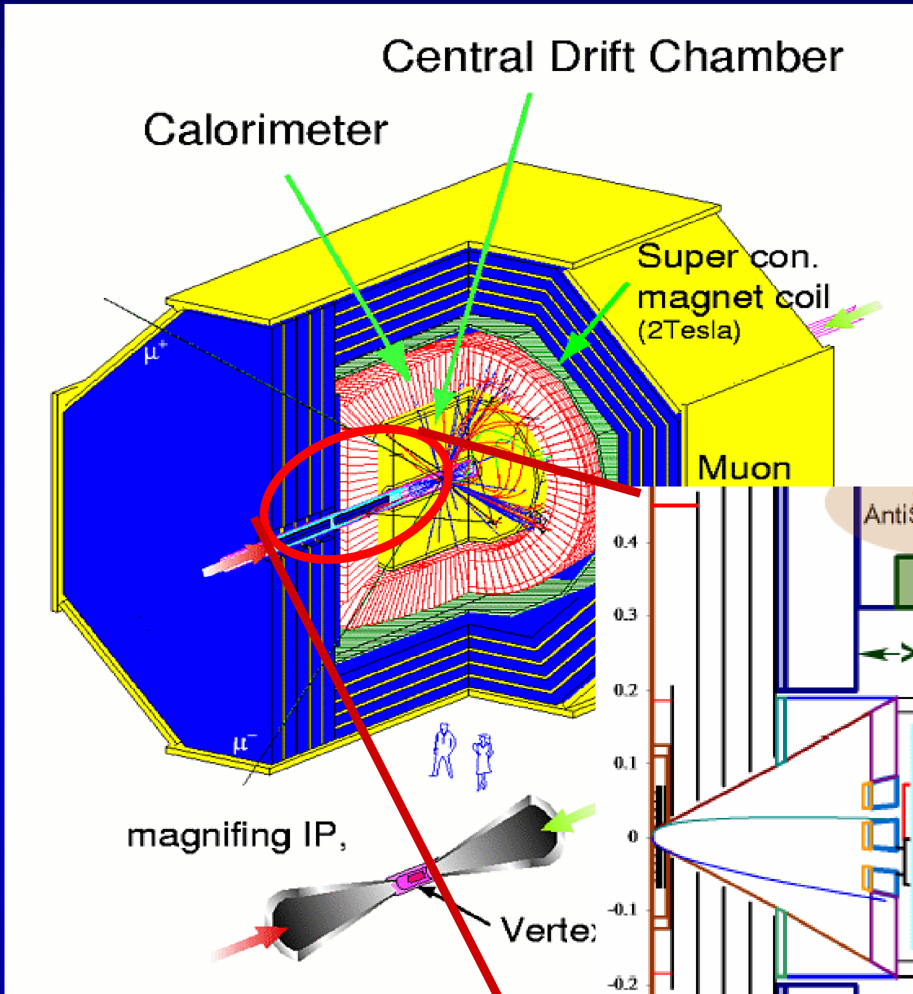
"Vinča" Institute of Nuclear Sciences, Belgrade
Royal Holloway, London,
BNL, Brookhaven, NY,
LAL, Orsay
Yale Univ.

Goal-Design and R&D for:

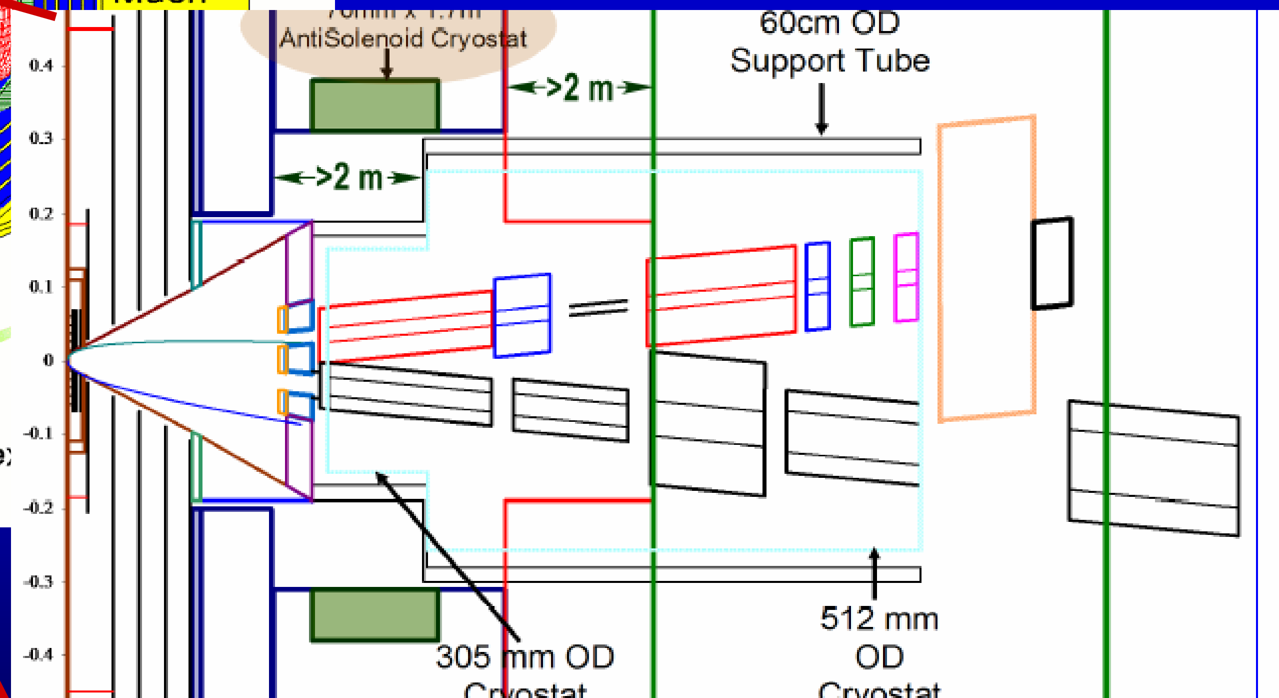
- BeamCal
- GamCal
- LumiCal

see: PRC R&D 01/02 (2002)

The ILC Detector, e.g. GLD

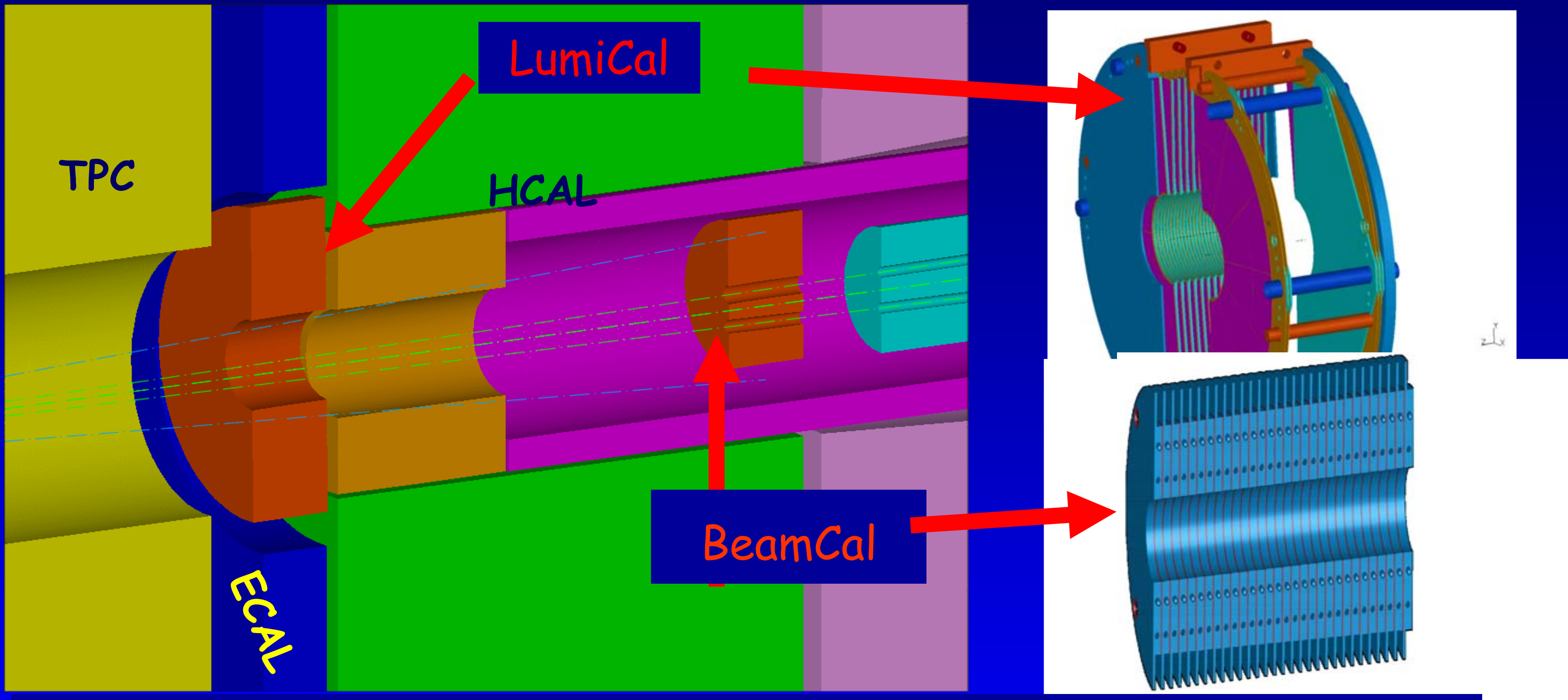


And the very forward region, e.g. SiD



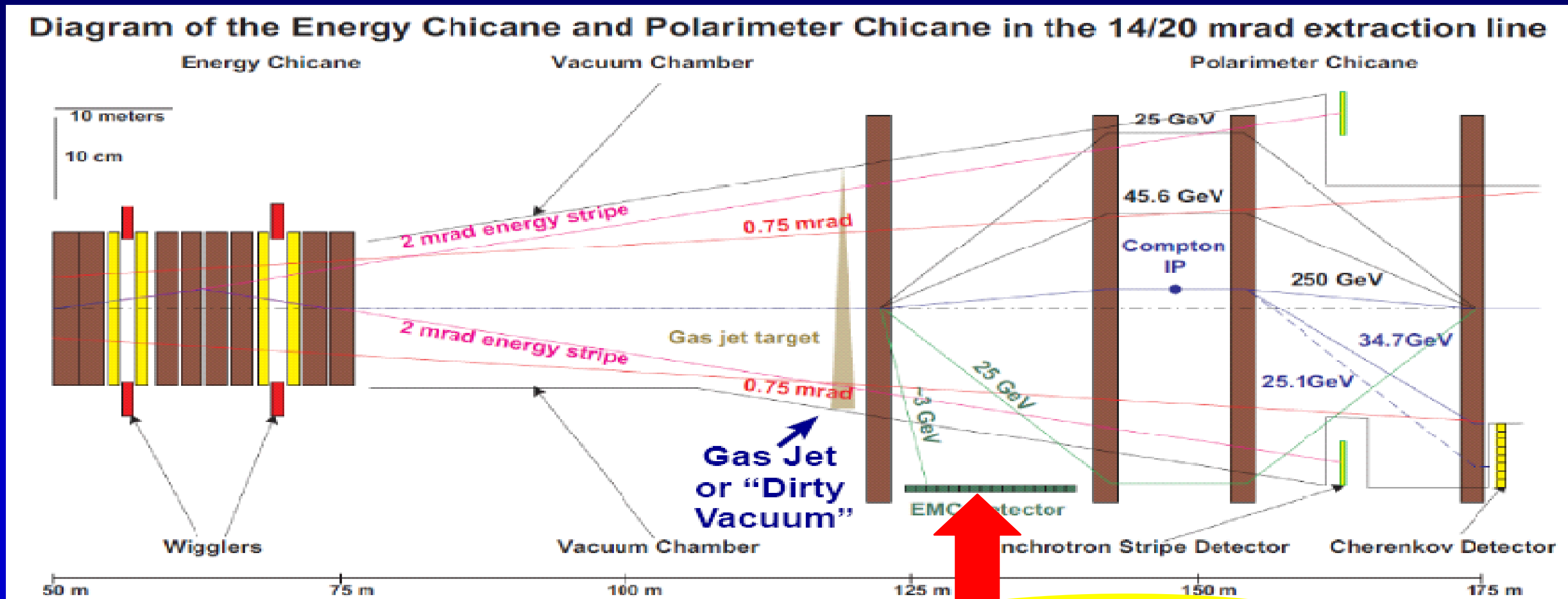
Simulations, Design and Functions

BeamCal and LumiCal (Example LDC, 20 mrad):



- design relatively advanced
- precise (LumiCal) and fast (BeamCal) luminosity measurement
- hermeticity (electron detection at low polar angles)
- mask for the inner detectors

GamCal



EM Calorimeter
130 m downstream

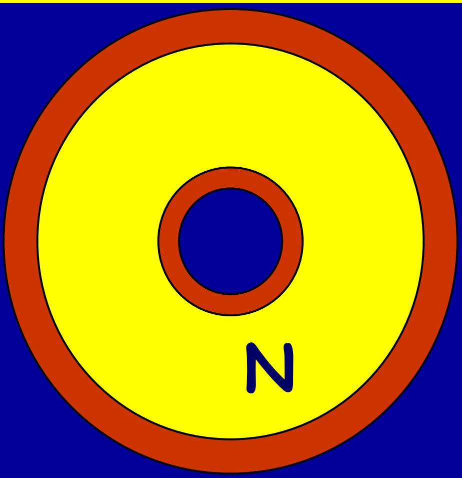
- design work ongoing
- detect the flux of photons by converting 10^{-6} of the intensity (Gas-Jet target)
- detect ‘wrong sign’ e^{+-} , number and spectrum correlated with the photon intensity and energy distribution

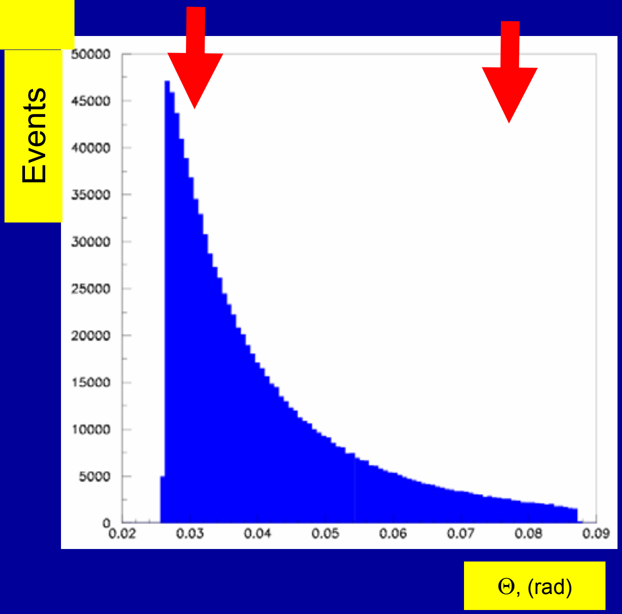
Measurement of $\mathcal{L}$

$$\mathcal{L} = N / \sigma$$

Count Bhabha events

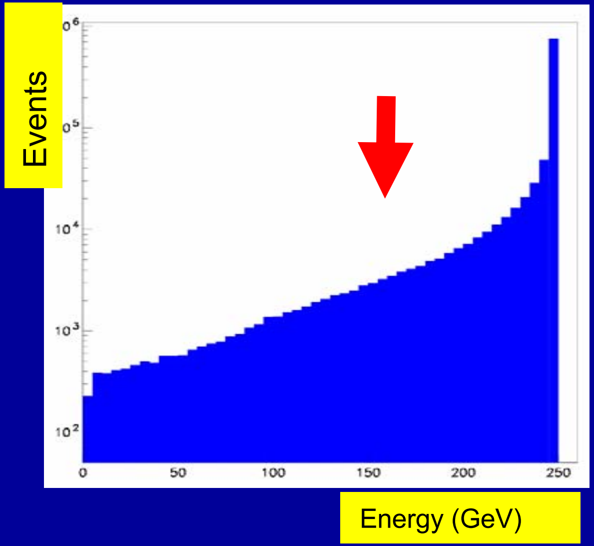
From theory





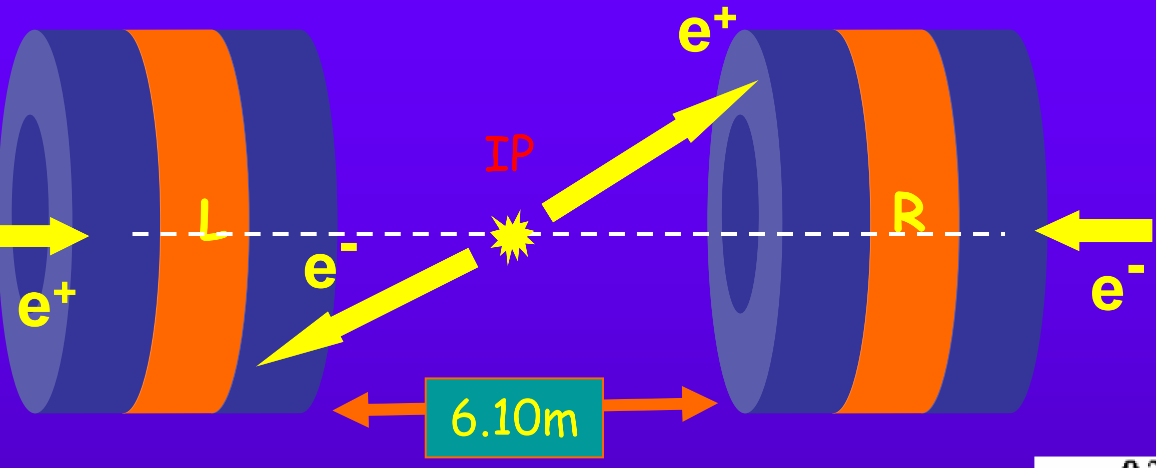
Goal: Precision ~10^{-4}

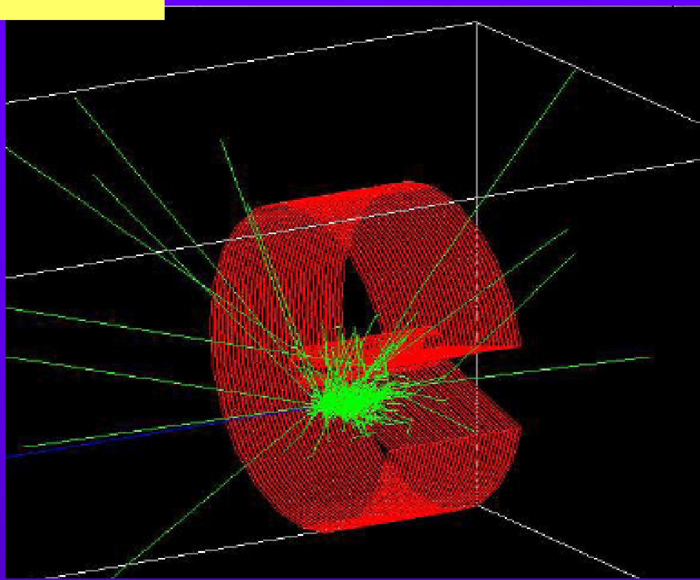
	Min	Max
R	~10 cm	~25 cm
θ	33 mrad	80 mrad

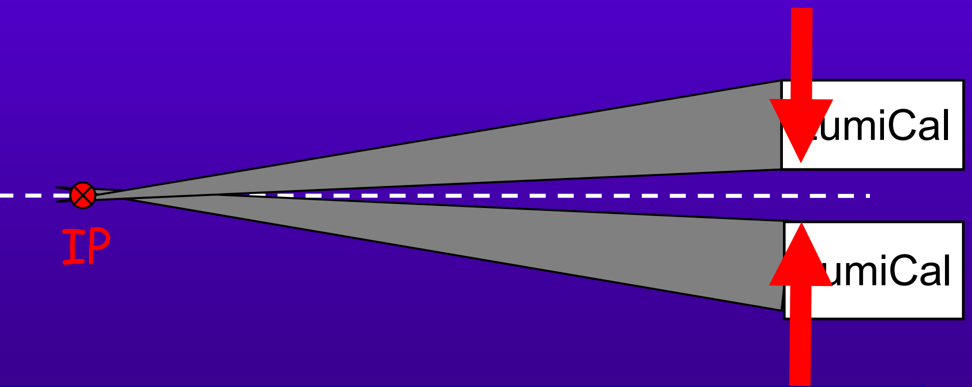


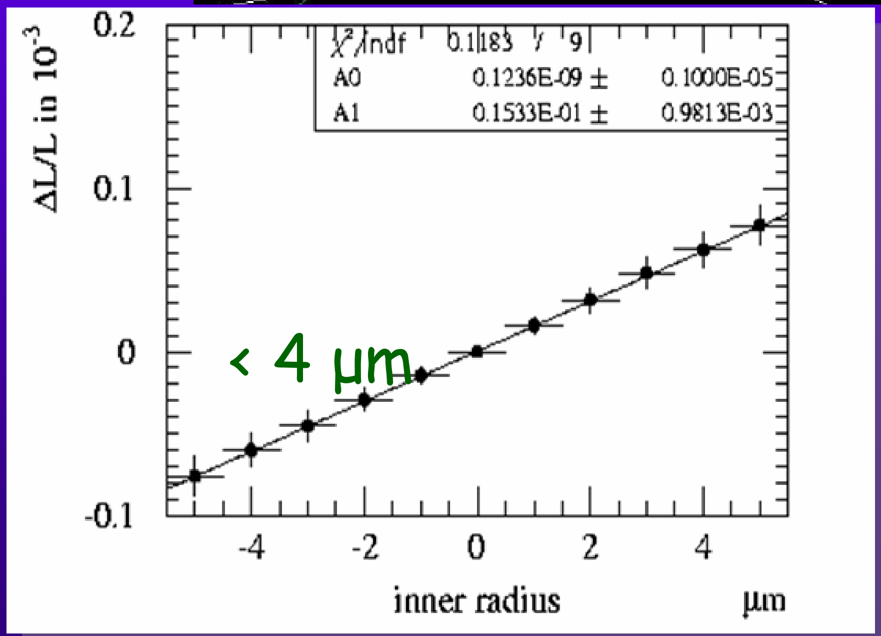
Requires theoretical cross-section with the necessary precision; contacts to theory groups in Zeuthen, Cracow, Katowice theory groups (two loop calculation)

Requirements on LumiCal







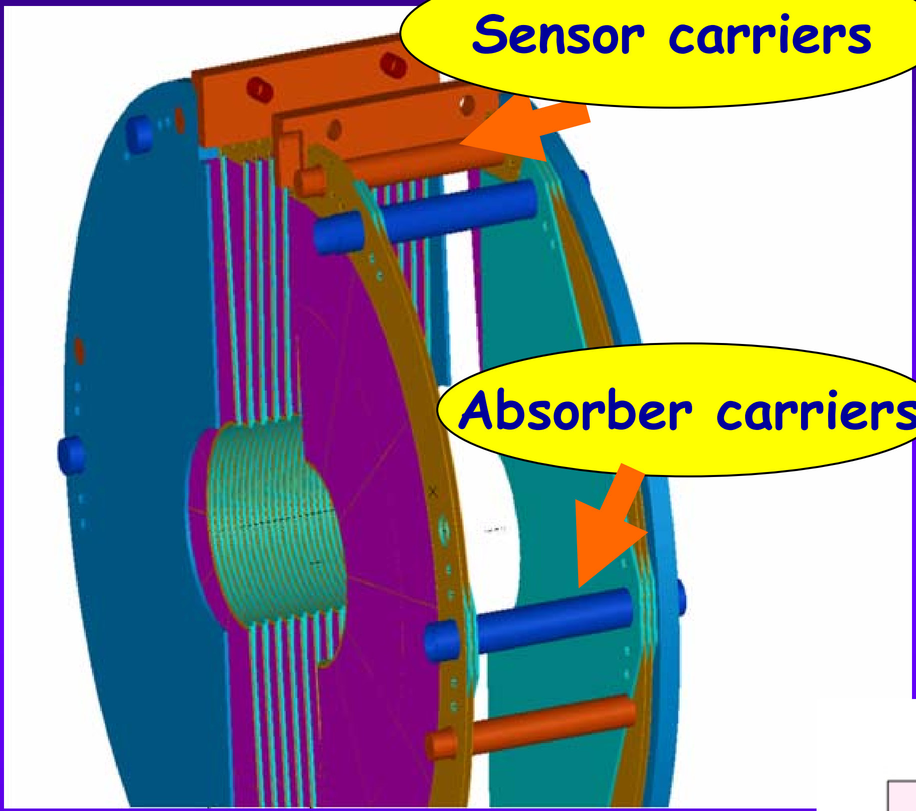


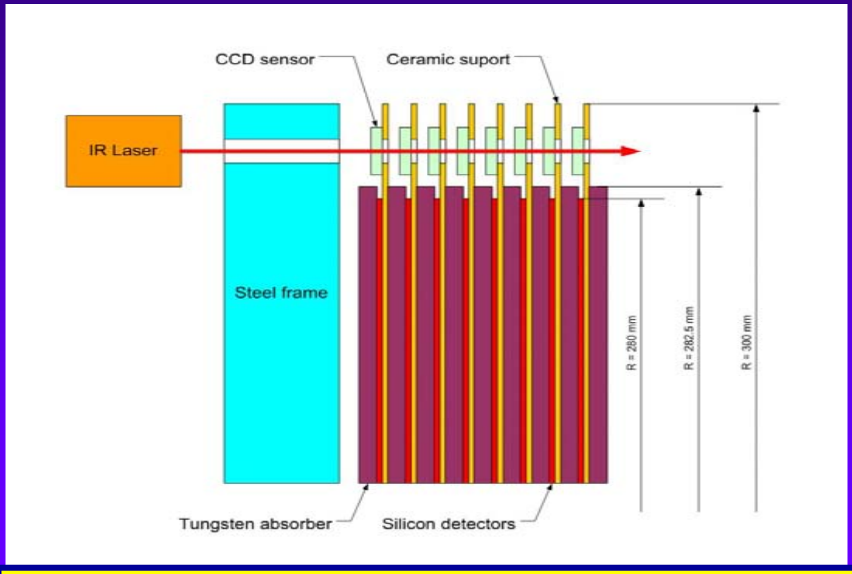
Inner Radius of Cal.: < 4 µm

Distance between Cals.: < 60 µm

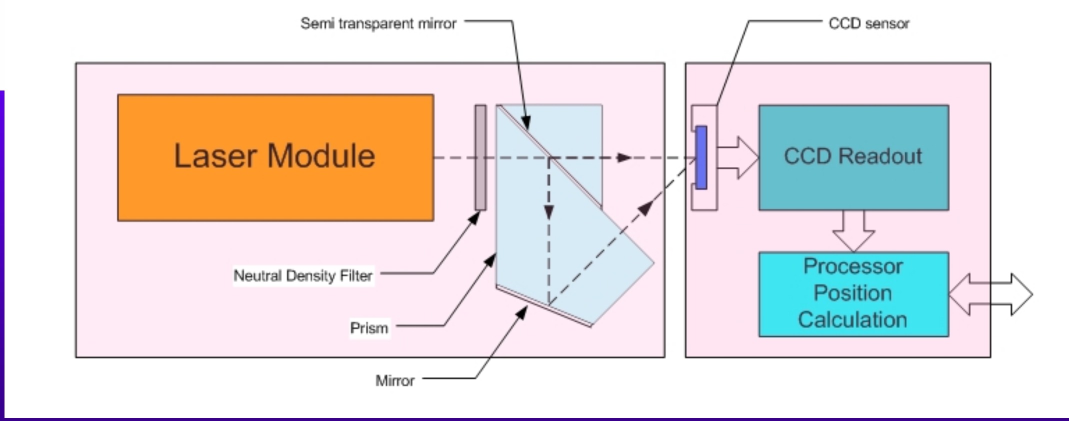
Radial beam position: < 0.7 mm

Mechanical Frame and Alignment





Alignment and position control using Laserbeams

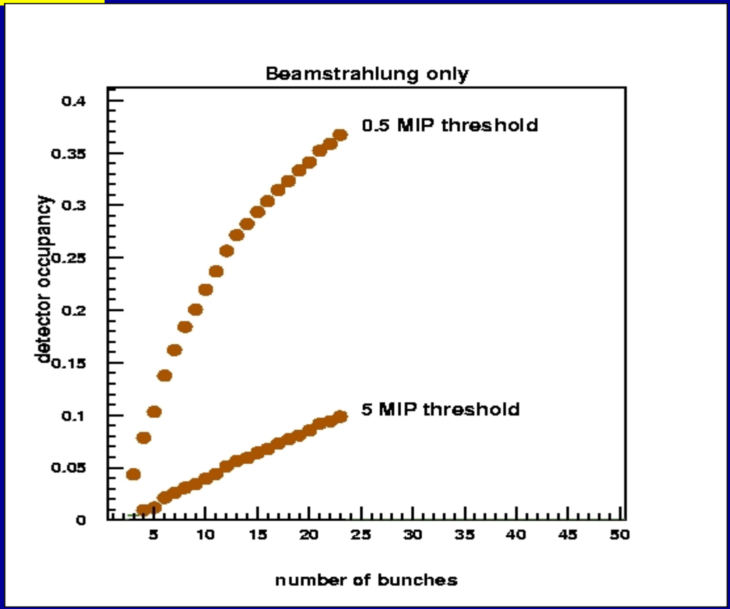


Decouple sensor frame from absorber frame

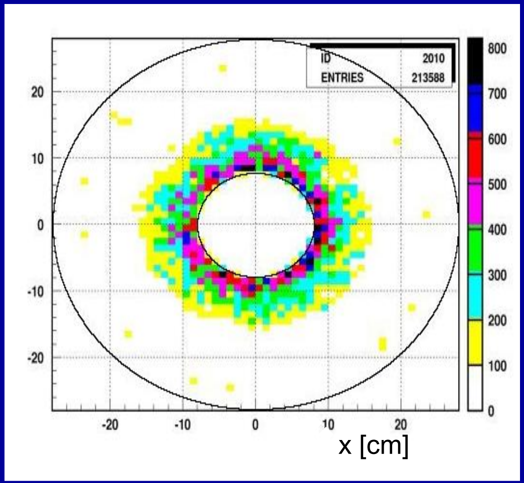
Occupancy

LumiCal

Remnant background from Beamstrahlung



+background from two photon events (under work)



+ Bhabha signal

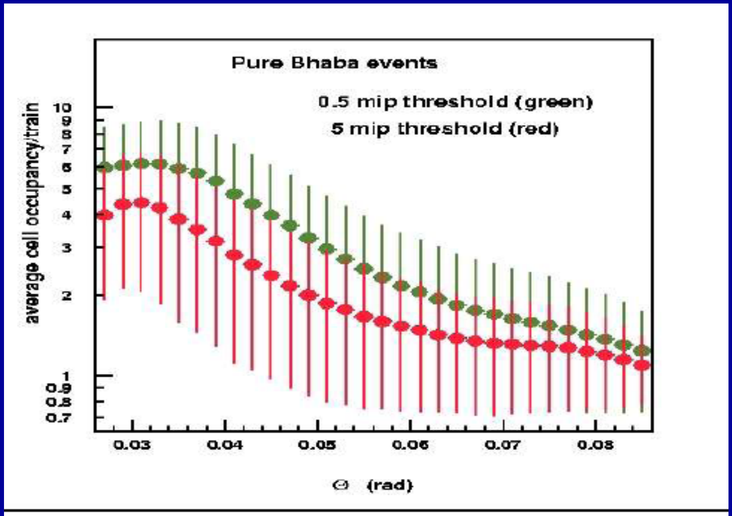
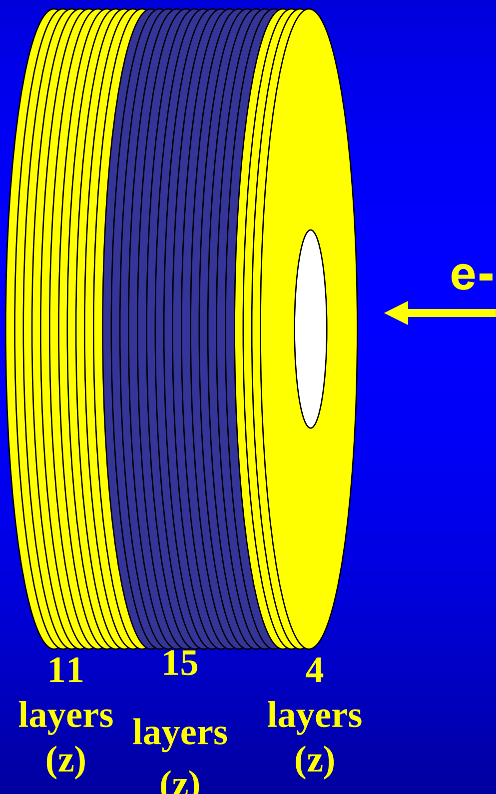


Fig.3 *Average channel occupancy per train for pure Bhabha events*

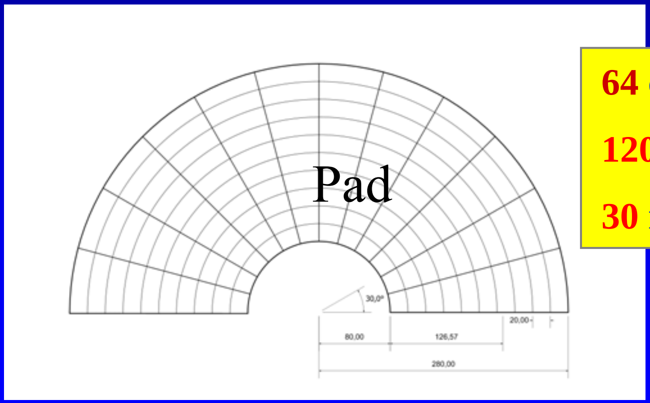
LumiCal, present understanding

Maximum peak shower

- 10 cylinders (θ)
- 60 cylinders (θ)



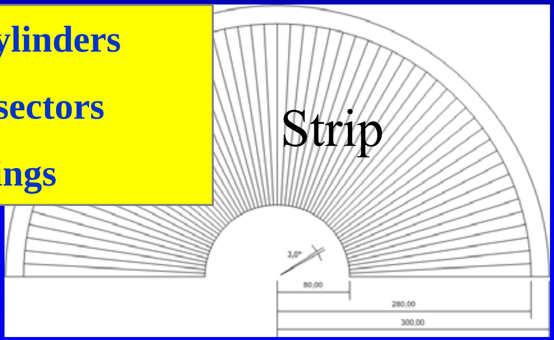
Every second ring:



64 cylinders

120 sectors

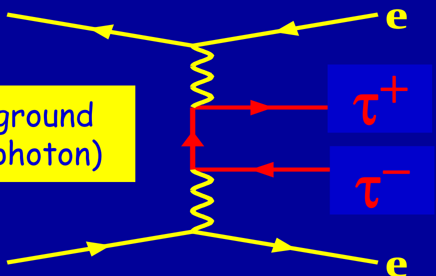
30 rings



Parameter	Pad Performance	Strip Performance
Energy resolution	$25\%(\sqrt{GeV})$	$25\%(\sqrt{GeV})$
θ resolution	$3.5 * 10^{-5}$ rad	$2.1 * 10^{-5}$ rad
ϕ resolution	10^{-2} rad	10^{-3} rad
$\Delta\theta$	$\sim 1.5 * 10^{-6}$ rad	$\sim 2.1 * 10^{-7}$ rad
Electronics channels	25,200	3720 (with bonding sectors) 13,320 (without bonding)

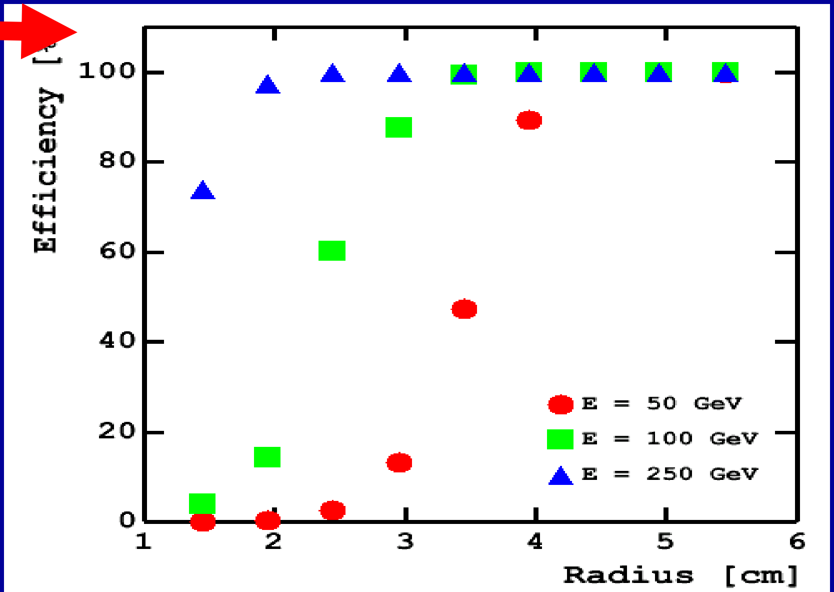
BeamCal

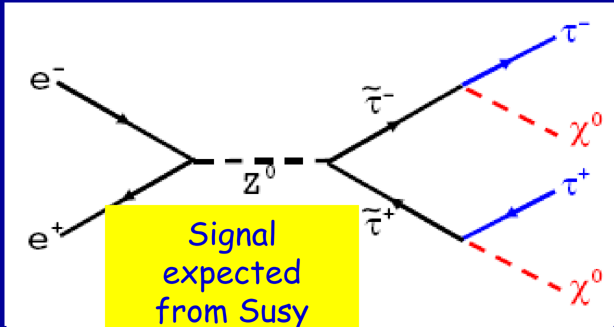
Efficient low angle electron veto
Why:
Background suppression in search channels, e.g.



Background (two photon)

Similar signatures, Two photon cross section much larger





$L = 500 fb^{-1}$

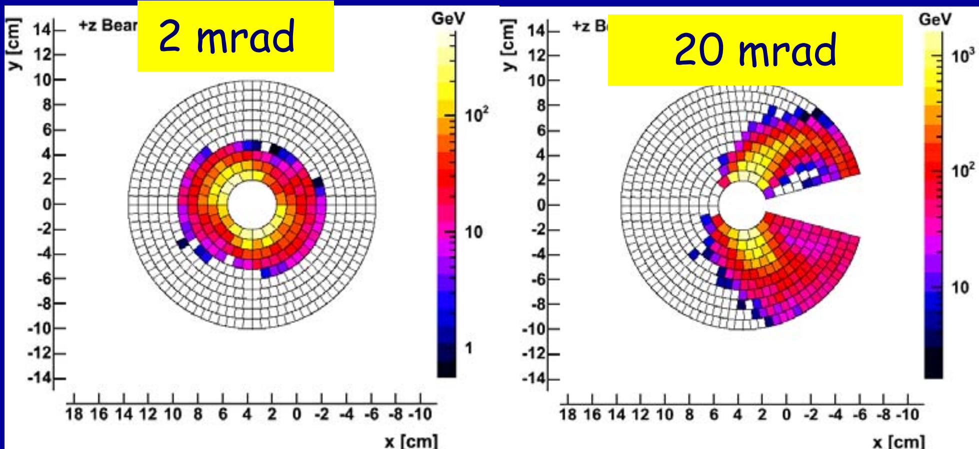
Number of **SUSY** events ~ 20

Number of unvetoed **2-photon** events:

Veto Energy Cut, GeV	75	50
Nominal	45	5
Low Q	40	0.1
Large Y	50	9
Low P	364	321
Nominal, 20mrad	396	349

BeamCal

Determination of beam parameters from beamstrahlung depositions on BeamCal:

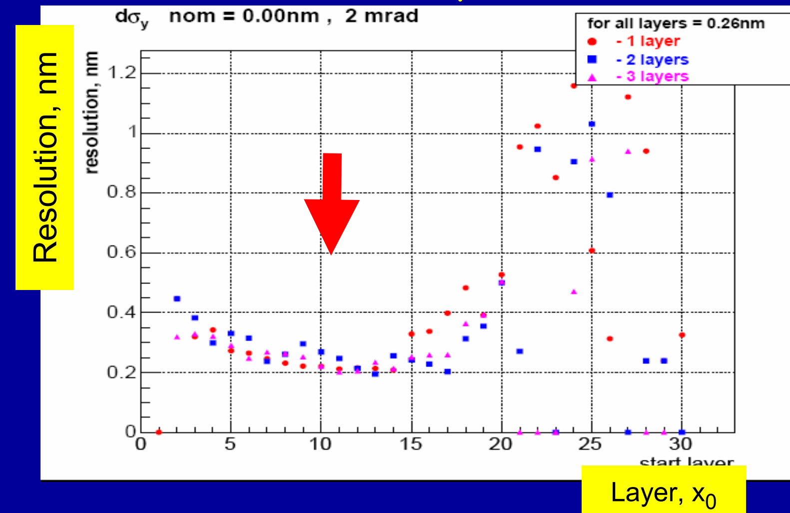


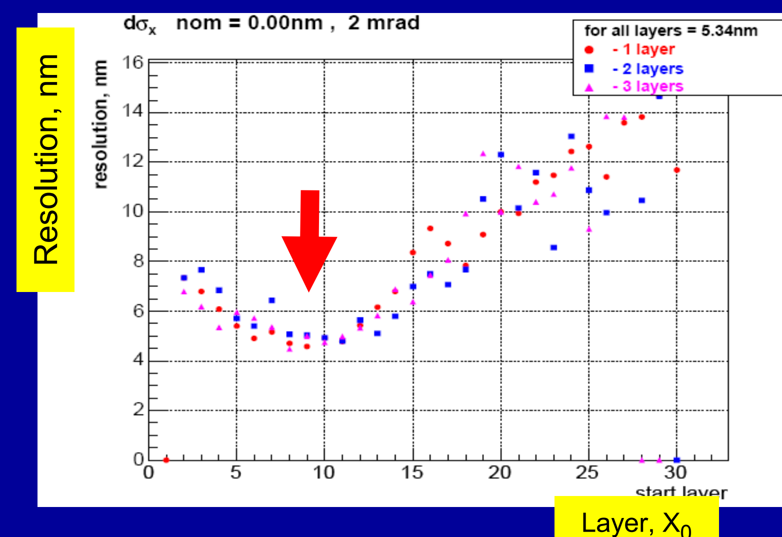
Quantity	Nominal Value	Precision
σx	553 nm	2.9
σy	5.0 nm	0.2
σz	300 µm	8.5

Question: how many sensor planes are really needed?

Seems sufficient to read out a few planes only (around 10 X_0)

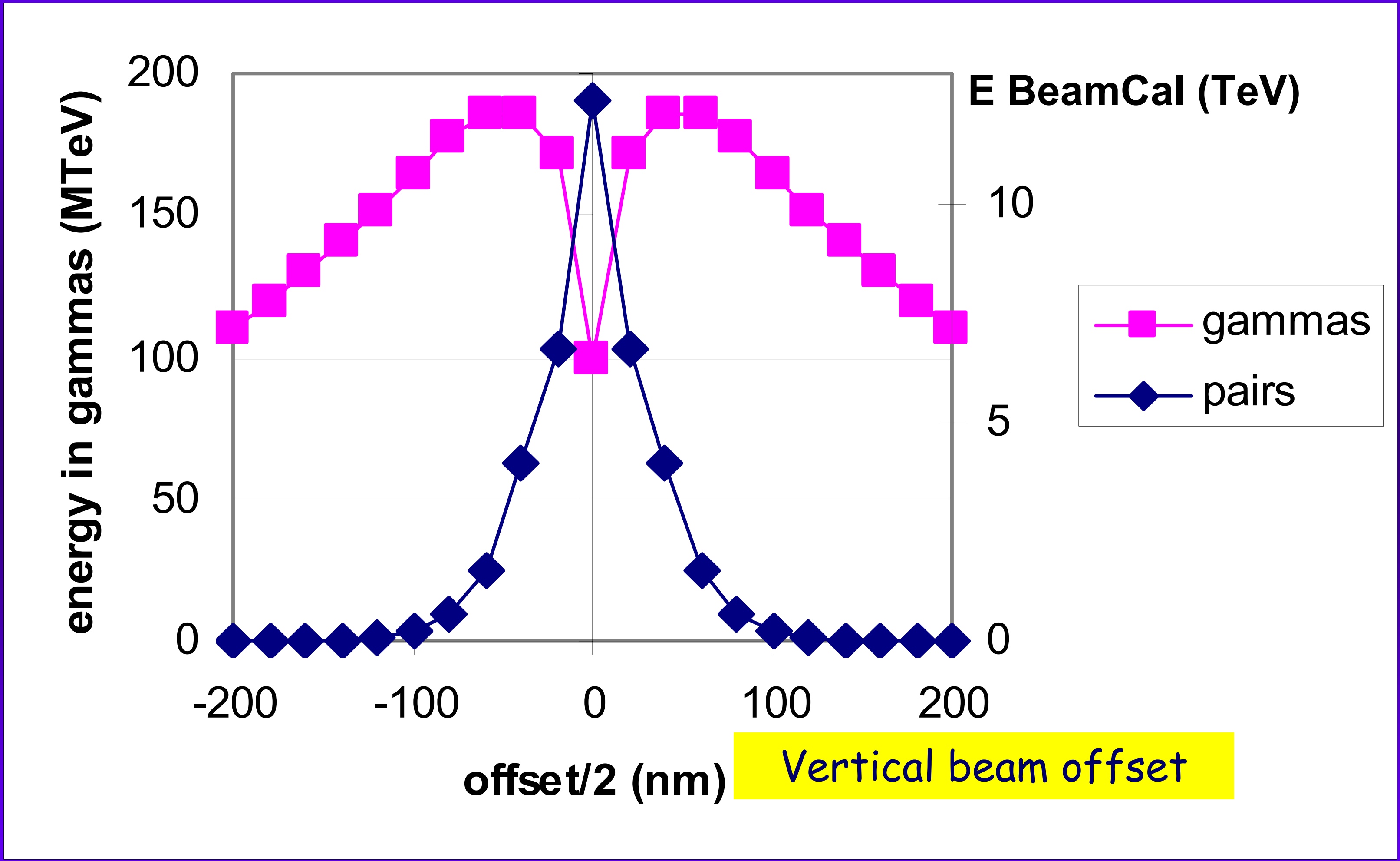
Full GEANT4 simulation:
Parameters: σ_x and σ_y





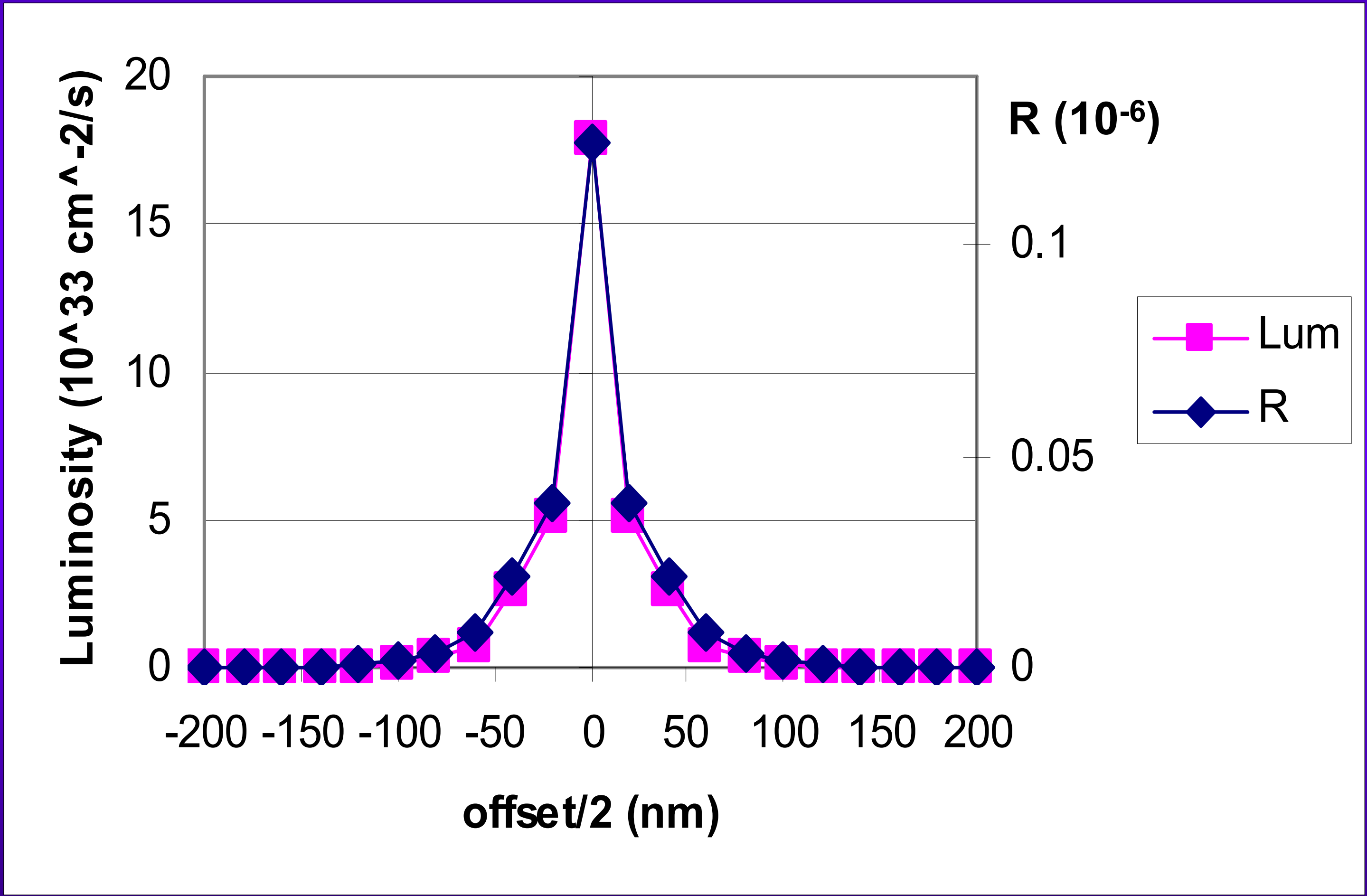
BeamCal & GamCal

Combine informations from pairs and photons (B. Morse)



GamCal &LumiCal

Ratio of energy depositions in BeamCal and GamCal:



Almost proportional to the Luminosity !!!

Readout Electronics Requirements

Readout- the challenges

e.g. BeamCal (LumiCal similar):

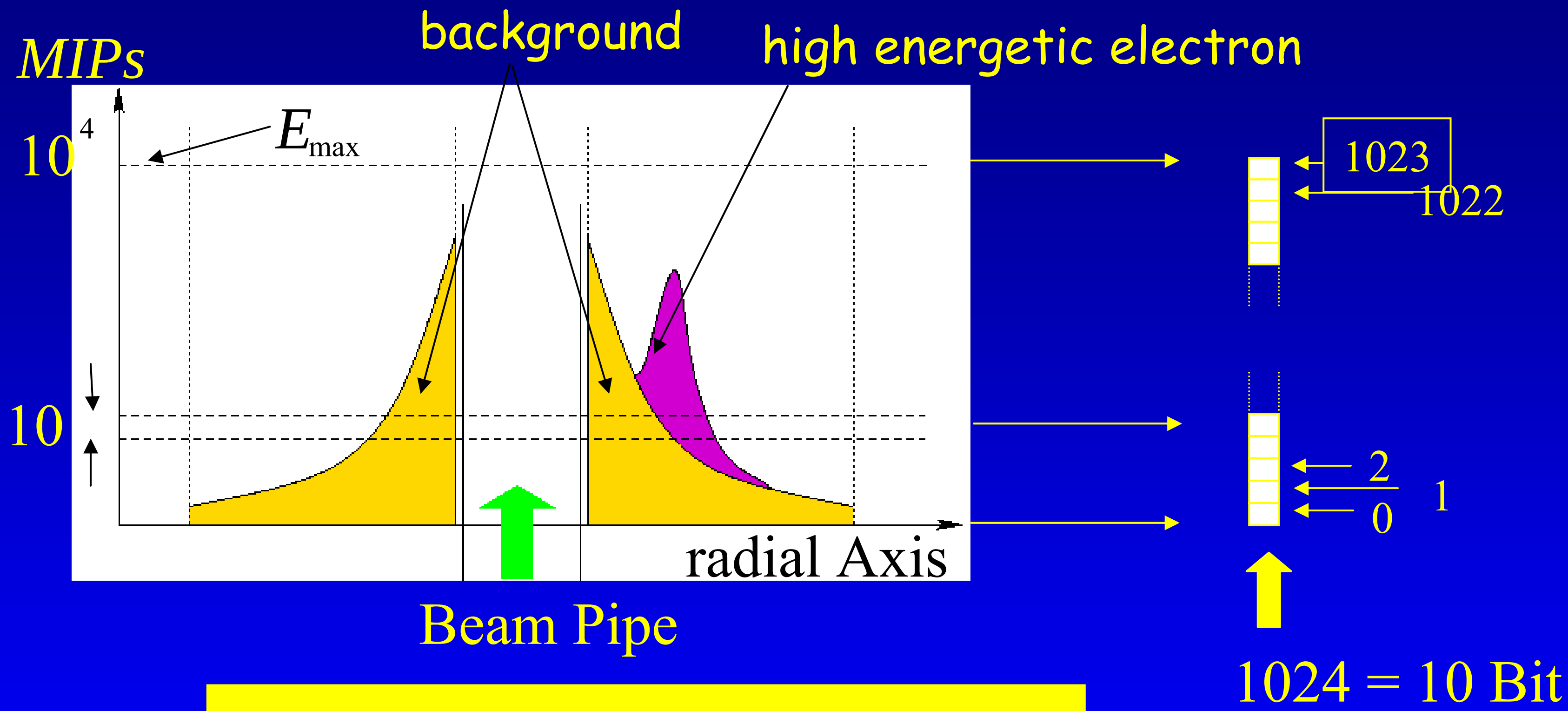
- 5 bunch trains per second (5 Hz)
- 3000 bunches within one train

- One bunch every 300ns, 150ns possible
-Each bunch to be registered
- O(10000) channels
- High dynamic range (1:10k)
- 10 bit ADC

- Data per train ~1 Gb
  (transmission during train ~1 Tb/s, during break ~3 Gb/s)

- Radiation hardness to be considered
- Compact detectors: low power & little space

Digitization

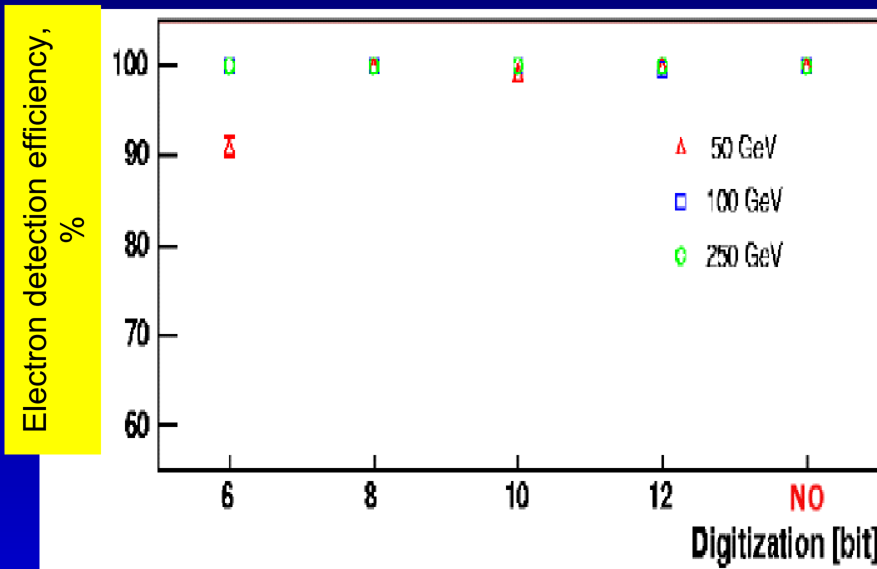


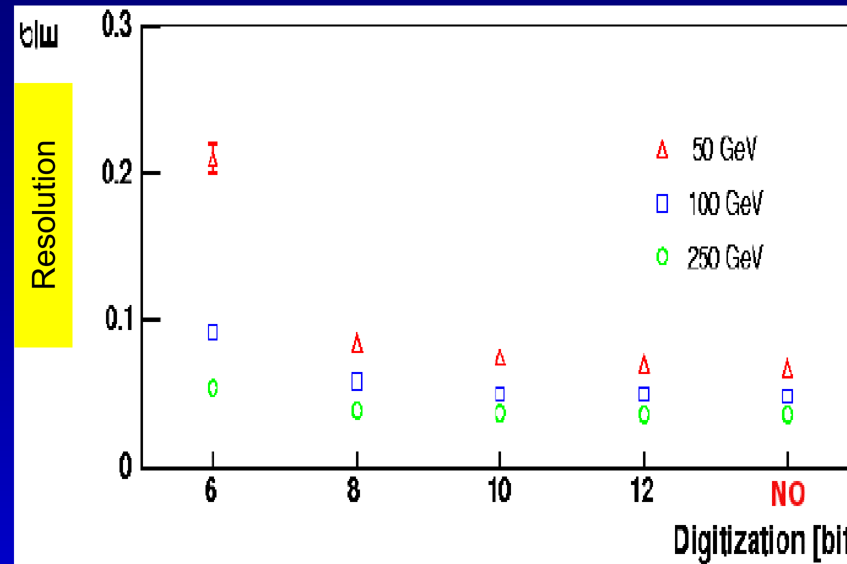
$$1024 \mathrel{\hat{=}} 10^4$$

$$1\,(\mathrm{LSB}) \mathrel{\hat{=}} 10\ \mathrm{MIPs}$$

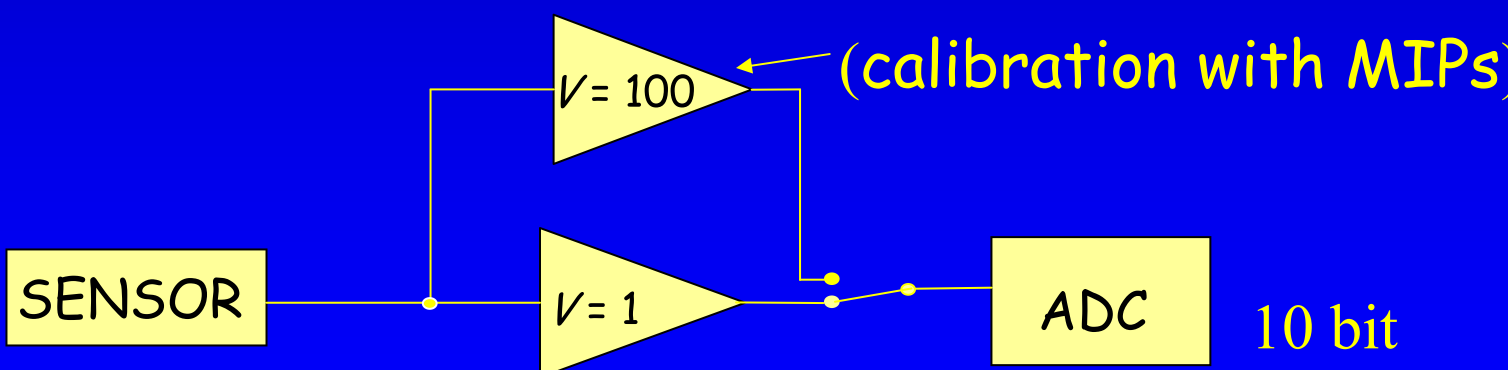
$$\pm 1\ \mathrm{LSB} \mathrel{\hat{=}} \pm 10\ \mathrm{MIPs} \quad (10\ \mathrm{bit})$$

Digitization





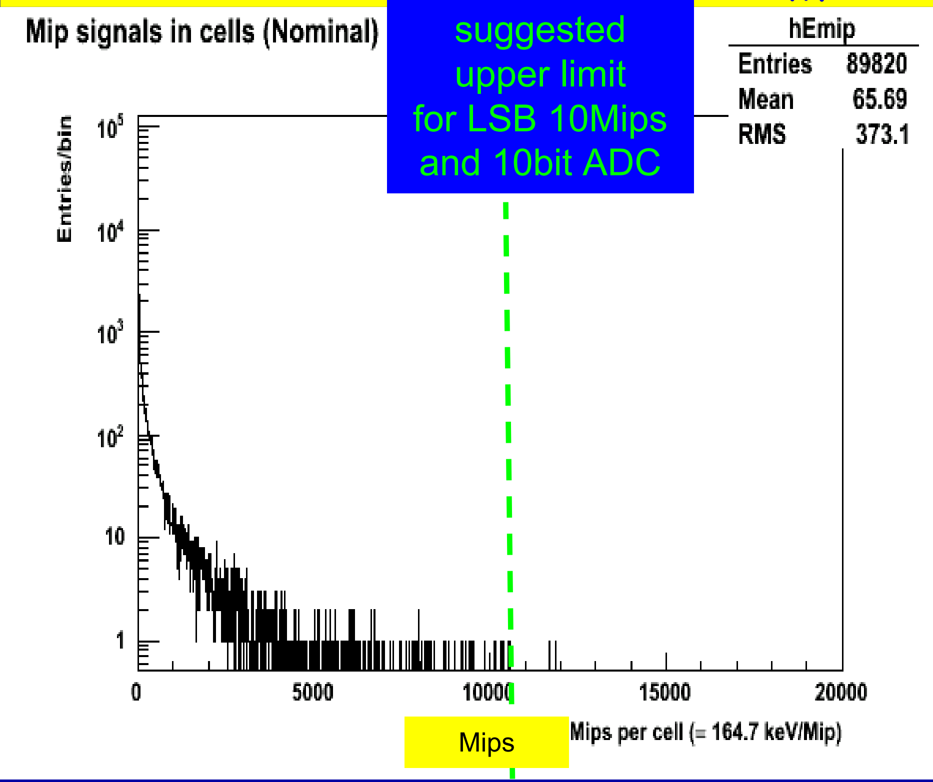
[0 – 100 MIPs] $1\,\mathrm{LSB} \triangleq 0.1\,\mathrm{MIPs}$



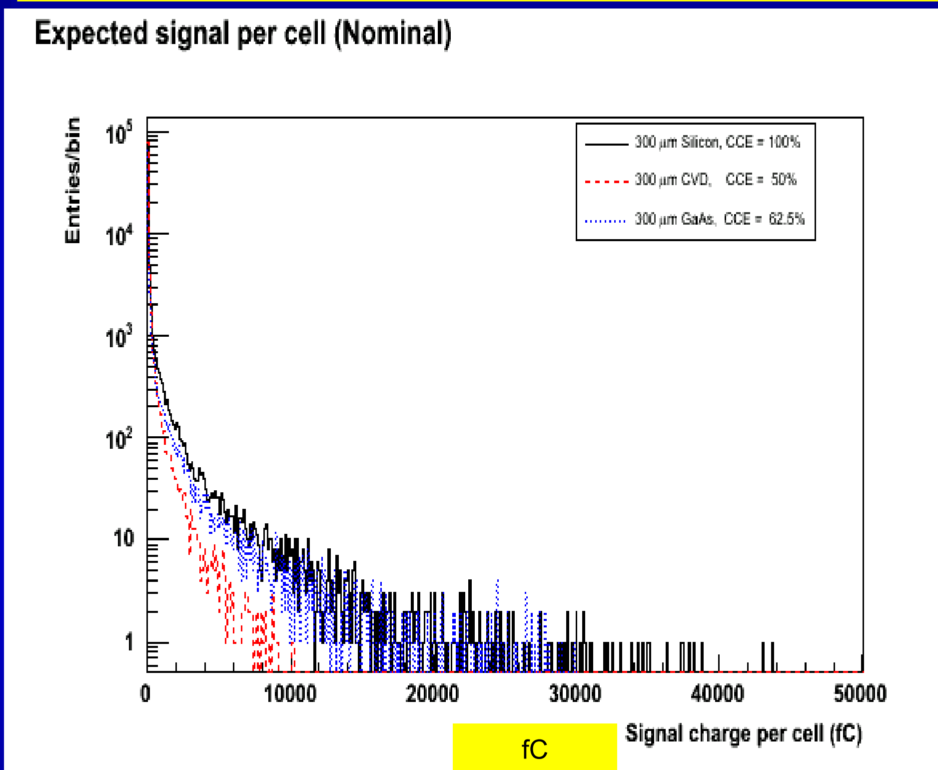
[0 – 10^4 MIPs] $1\,\mathrm{LSB} \triangleq 10\,\mathrm{MIPs}$

Signal Size

Assume: pad (cell) size ~ 0.8 R_M, Si



And other sensors (CVD D., GaAs)



- depends on the accelerator parameters
- Sensor material

Signal Size

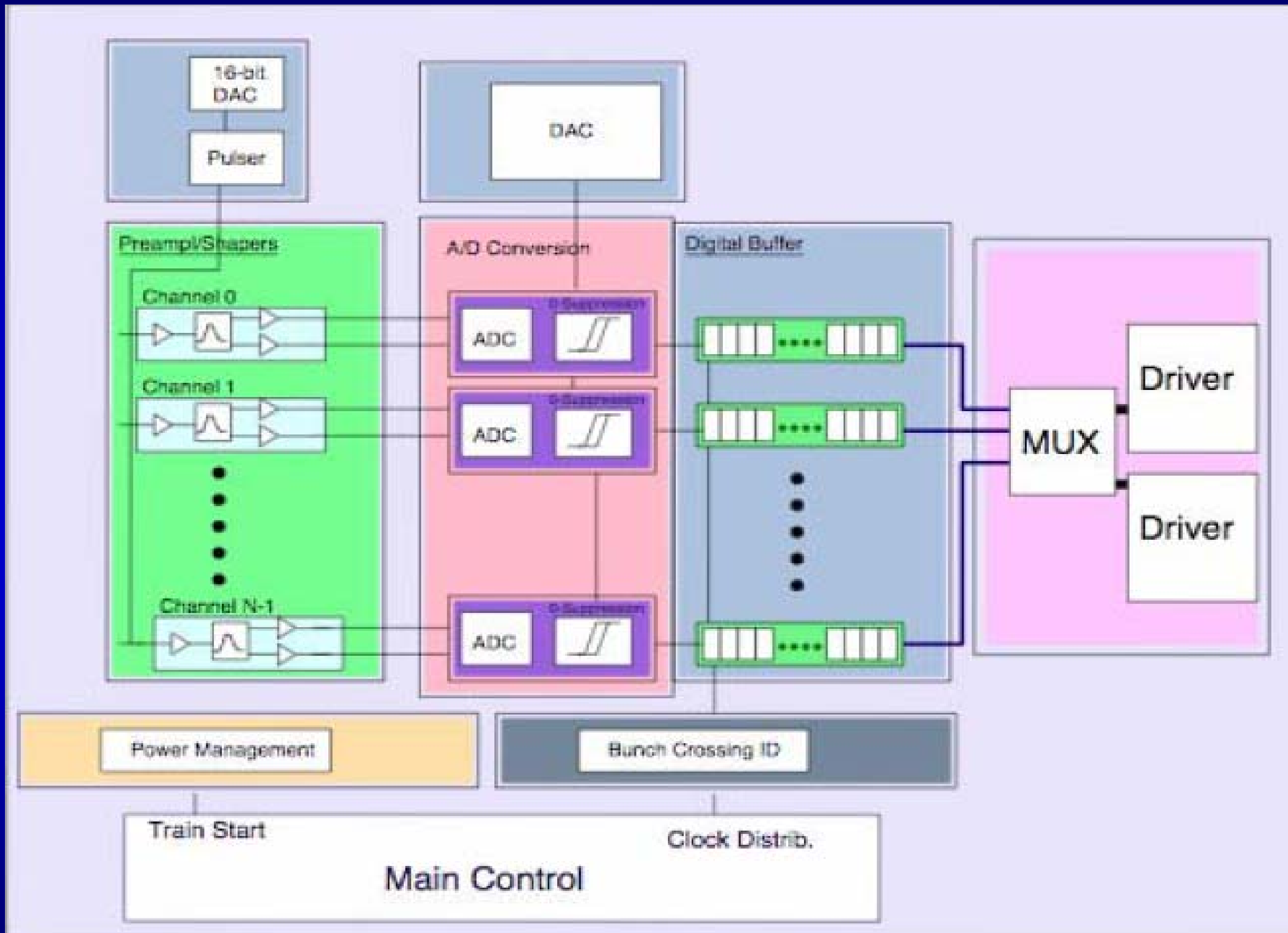
Sensor	efficiency charge coll.	thickness	ε_R, pF	C_{Det}	Q_{low} = 10 MIP	Q_{high} = 10^4 MIP
Si	100 %	300 µm	11.9	19.3 pF	36.9 fC	36900 fC
pCVD diamond	50 %	300 µm	5.7	9.25 pF	8.7 fC	8700 fC
GaAs	62.5 %	300 µm	12.9	20.9 pF	40.1 fC	40100 fC

Detector capacity calculation based on:
average cell size of 0.55 cm² (compare to slide 2)

Note that this does not include any signal routing!

In LumiCal: signal range from 1 fC (0.25 mip) up to 15 pC

A possible scheme

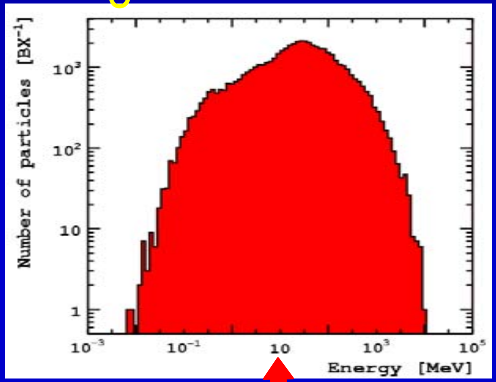


Test-beam studies

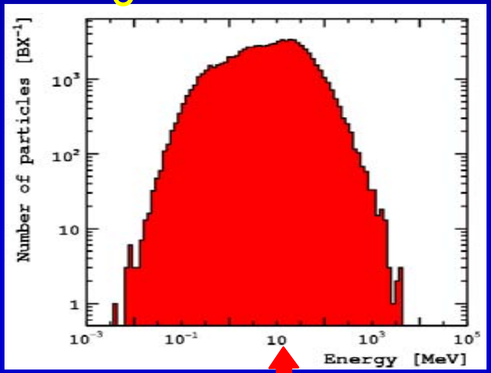
Radiation hardness

Energy of shower electrons inside the sensor:

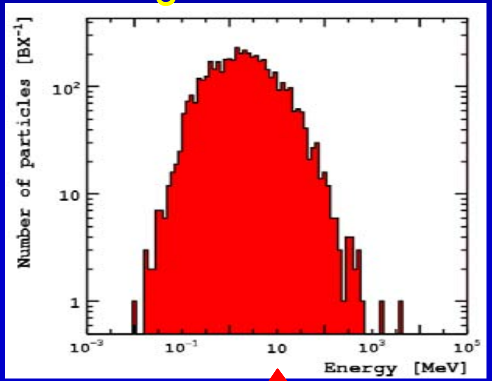
$2X_0$



$6X_0$



$20X_0$



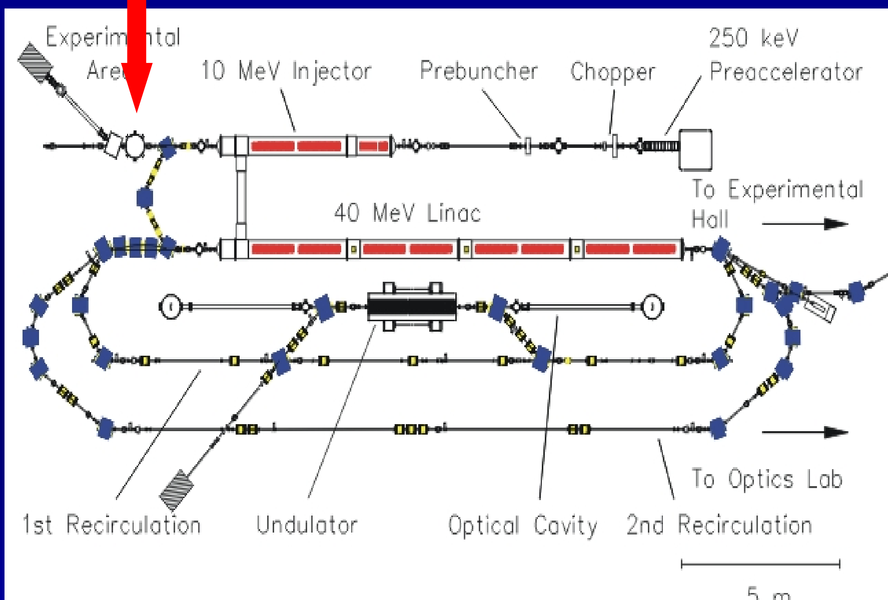
Radiation hard against electromagnetic radiation in the 10 - 100 MeV range !

Radiation hardness

Beams available:

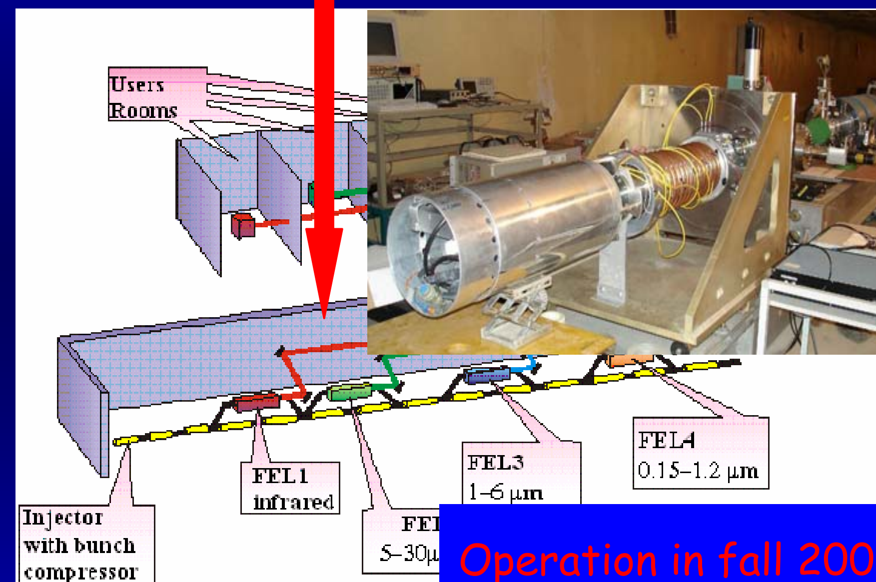
SDALINAC (TU Darmstadt)

10 MeV



JINR LINAC 800

20-40 MeV

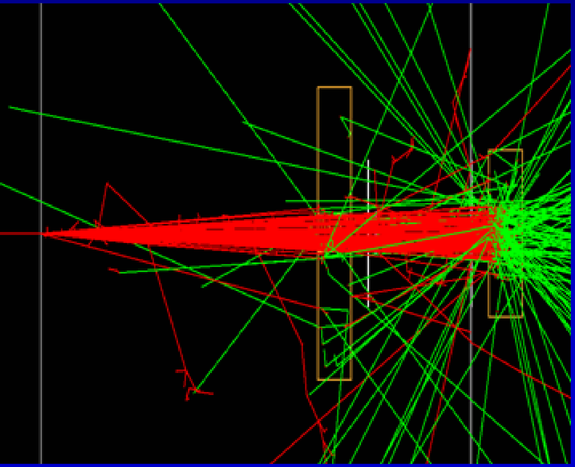


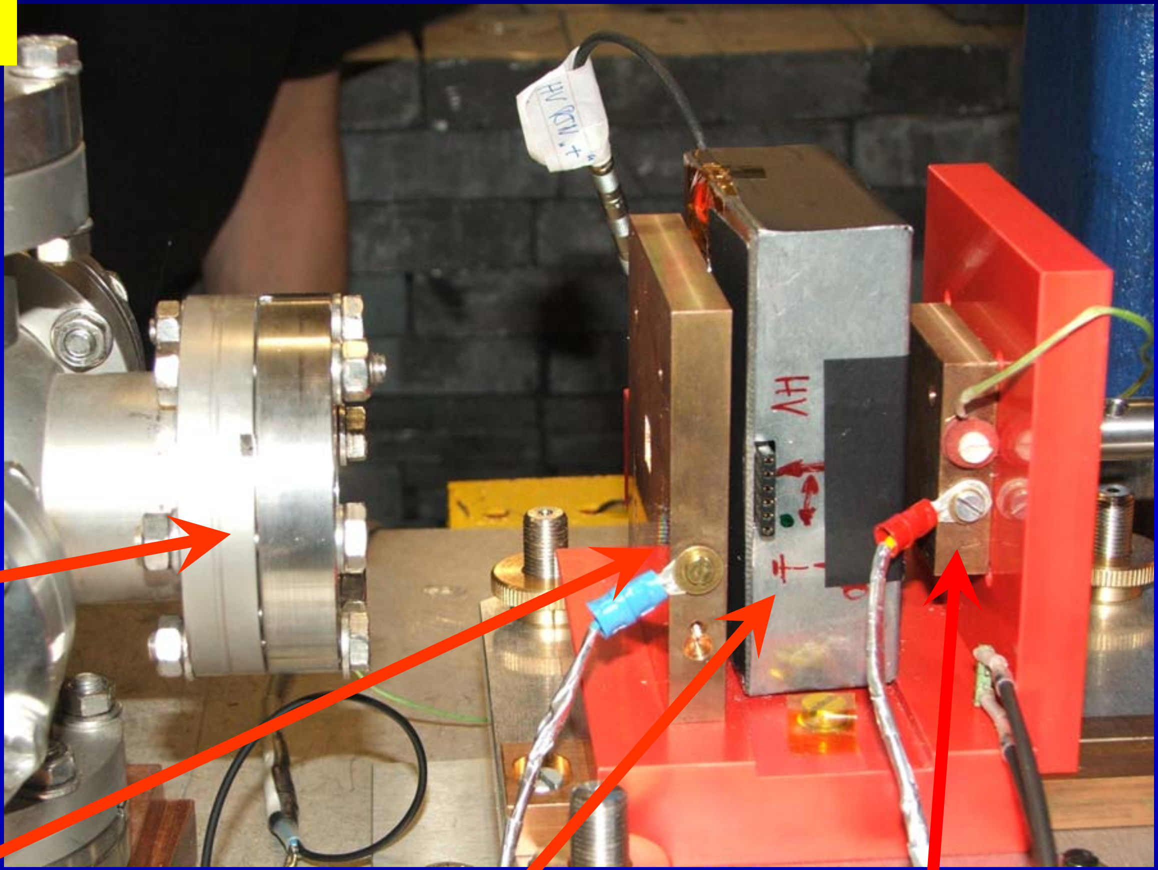
Operation in fall 2007

beam currents from 1 to 100 nA (10 nA ≈ 50 kGy/h)

Radiation hardness

The testbeam setup





exit window
of beam line

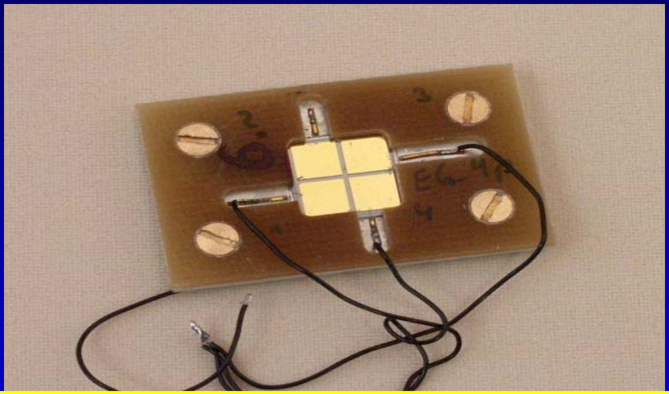
collimator (I_{Coll})

Faraday cup (I_{FC}, T_{FC})

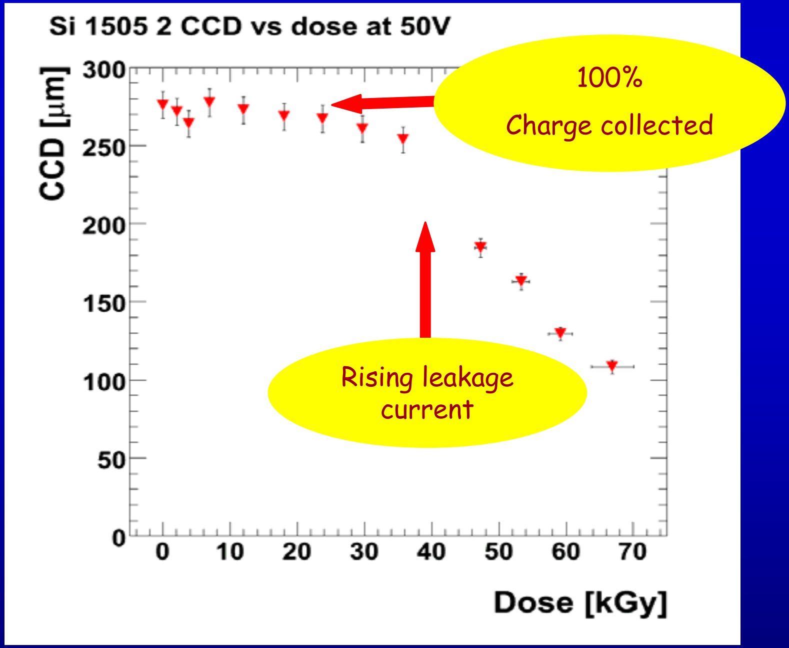
sensor box (I_{Dia}, T_{Dia}, HV)

Radiation hardness

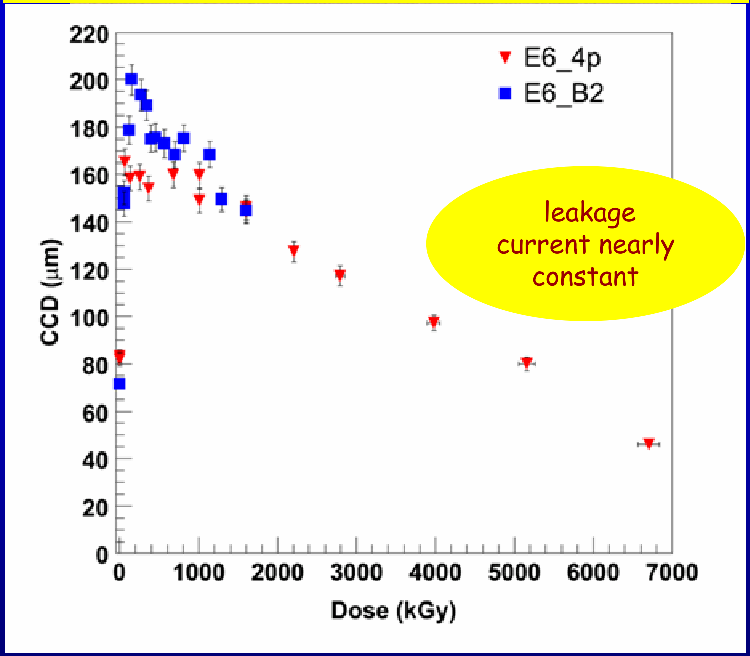
Results from 2006 (DALINAC)
Si and diamond sensors:



Si pad sensor



Diamond sensor after ~7 MGy

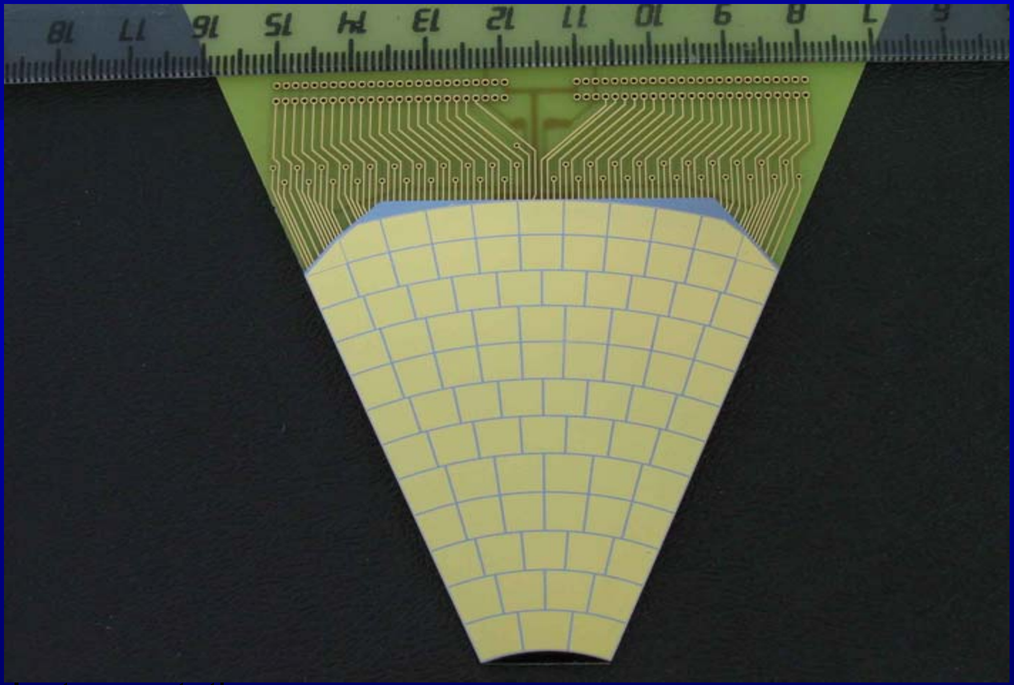


Radiation hardness

Plans for 2007/2008

- Repeat measurements with new diamond samples
- Measurements with lower dose rates
- Test alternative sensor materials
  - GaAs (produced by Russian Collaborators)
  - SiC (collaboration with BTU, Cottbus)
  - Rad. hard Si (BNL?)

GaAs Segment prepared for tests

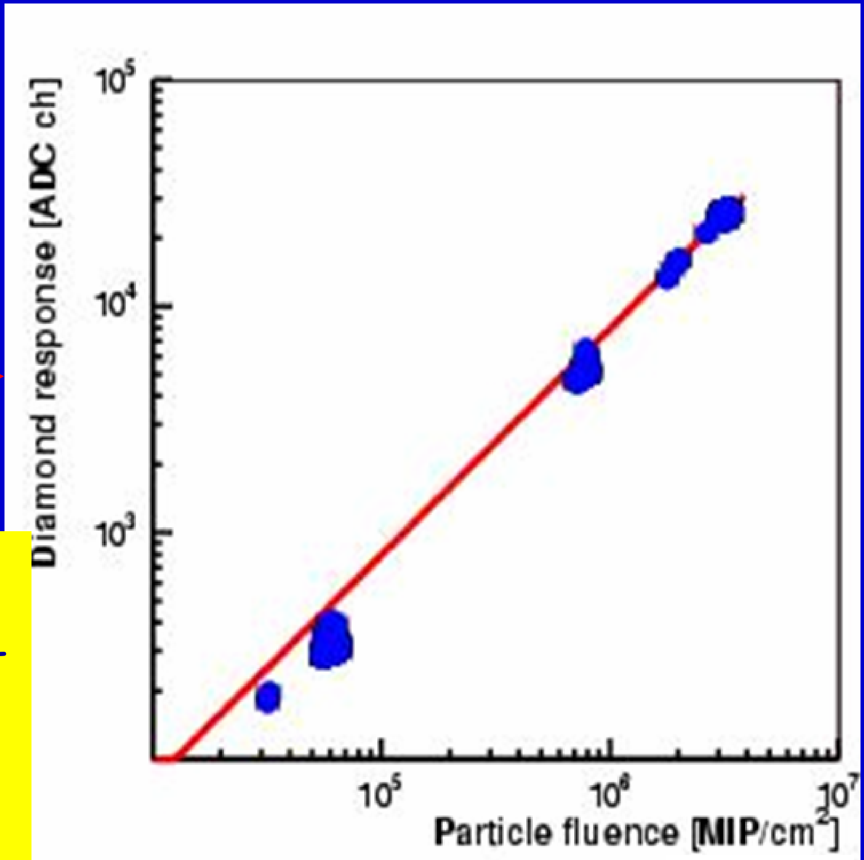


Linearity and dynamic range

CERN PS (CMS)

Energy (mixed beam): few GeV
10^3 – 10^6 particles in ~10 ns

Test of several diamond sensors,
1 cm^2 area, 500 μm thick,
Results reasonable



/10 ns

Plans 2009/10

-Repeat and refine previous measure-
ments (better flux calibration)

-Study new sensor materials

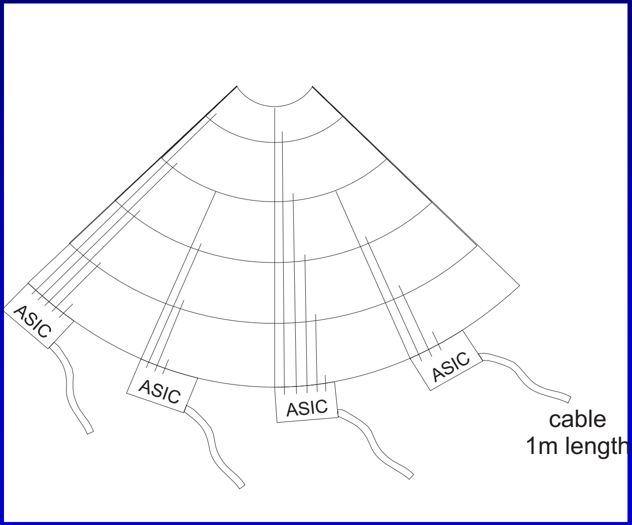
Compactness

Goal:

Thin instrumented sensor plane prototypes (< 1mm thickness)

- Function test of assembled sensor planes,
- Channel-to-channel homogeneity,
- Cross talk,
- Performance at the edges.

sensor carrier



Plan 2007/2009
Use a few GeV electron beam at DESY, EUDET infrastructure

Prototype Calorimeter Tests

Finally prototypes of BeamCal and LumiCal must be tested in a beam to proove the performance of the full system

Plan, not before 2010:
Test in an electron beam of ~100 GeV at CERN or Fermilab

prototype of GamCal

Plan: ~2009 (??)
1-20 GeV electron beam, SLAC?
High (100 GeV) beam for background studies

Summary

- R&D for the very forward region is independent from the detector concepts
- From similations: Design of BamCal and LumiCal relatively advanced, GamCal is coming up
- Mechanics design – first ideas
- Integration in the detector to be done later
- Radiation hard sensors not yet settled;
  - we consider 'backup materials', like special silicon and GaAs
- Read-out electronics will be a challenge
  -different from 'standard' calorimeters, fast digitisation and processing, large amount of 'raw data'

Effort on hardware developments is just increasing